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INTERIOR BALLISTIC EVALUATION OF HIGH-FLAME TEMPERATURE PROPELLANTS IN 20mm AMMUNITION AND ASSESSMENT AS AN EROSION TEST DEVICE

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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M9 propellant	
Erosion test apparatus	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (idk)

Gun barrel wear tests have uncovered the need for a small scale device to test barrel treatments like "thick" chromium. Small caliber barrels have traditionally served this role, but results with high-firing rates used to produce measurable wear are ambiguous. An ideal erosion test device would be a small caliber gun with standard projectiles, cartridge cases and propellants which would produce wear comparable to wear in large-caliber guns.

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20. ABSTRACT (Continued)

Interior ballistic tests were done with M2 or M9 propellant in place of the standard ball powder in the M55A2TP-T round to determine charge masses which would not exceed the peak chamber pressure of the reference M55A2TP-T round. The wear produced with the high-flame temperature propellants was estimated with the Frankle-Kruse empirical formula. The results showed an M9 propellant could be loaded to the same charge mass as the reference WC870 ball powder with a lower peak chamber pressure but 100 m/s higher velocity. The wear estimated for such a round is 5μ/shot, comparable to wear-limited Army guns, but less than the desired 25 μ/shot (1 mil/shot) for an erosion test device. Hence the 20mm gun with M9 propellant could be useful for evaluating chromium-plating for existing guns, but it has too little wear for conveniently assessing future platings and coatings.

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I. INTRODUCTION

Recent attempts to assess the wear reduction by electroplating the bore surface of large-caliber guns have proved inconclusive.[1,2] The results clearly show "thick" chromium plate (0.12 to 0.25 mm) retards wear in the commencement of rifling region. Muzzle wear and chromium-plate spalling downbore render uncertain whether the accuracy life of the cannon has been increased significantly. In the instances where the chromium remained intact, it appeared wear life could be more than doubled.

These results reinforce the need for screening tests to evaluate platings. Wear tests with rapid-fire, small-caliber guns (traditional method) may not duplicate the wear in single-shot, high-velocity guns. In this type test, wear strongly depends on burst rate and burst length. Therefore, stoppages render the results meaningless for comparison purposes.

An ideal screening device would be a small-caliber gun with single-shot wear comparable to larger guns. Such a device should also use readily available barrels, cartridge cases, projectiles, and propellants. This report concerns interior ballistic tests with a 20mm M61 barrel firing M55A2 TP-T rounds with M2 or M9 propellant replacing the standard WC870 propellant along with estimates of wear.

II. EXPERIMENTAL

Firings were done in a 20mm M61 Mann barrel fitted with a "mini-hat" gauge in the chamber and another at the commencement of rifling. Muzzle velocity was measured with three Lumiline screens placed at known distances down range. The time for the projectile to reach each screen was measured with two redundant counters. Velocity was computed from the distance between screens and the time to traverse this distance. Velocity so computed was taken as velocity at the midpoint between screens; muzzle velocity was computed by linear extrapolation back to zero distance. The distance from the muzzle to each screen is listed below:

Screen	Distance to muzzle, m
1	2.3146
2	9.4504
3	14.494

[1] *J.A. Lannon and A.C. Vallado, "Effect of Chrome-Plating on Wear Characteristics and Ballistic Performance in the 155mm Artillery System," Proceedings of the 1980 JANNAF Propulsion meeting, CPIA Publication 315, March 1980.*

[2] *C. Musick and H. Jones, "Wear Tests of 105mm M68 Cannon With 10 Mil Chromium Plate," MTD Report in preparation.*

For the rounds fired with bore surface thermocouples, the "mini-hat" gauge was retained in the mid-chamber position, but the gauge located at the commencement of rifling was replaced with a bore surface thermocouple. The thermocouples were chromel-constantan type gauges furnished by Medtherm Corporation, with one microsecond response. The junction of the thermocouple was recessed less than 0.03 mm from the land surface to protect the junction from mechanical damage. A series of 5.56 mm firings concluded that recessing the thermocouple 0.03 mm did not change the maximum measured temperature.

The high-flame temperature propellants tested during this experiment are listed in Table 1. Table 2 lists the nominal compositions with flame temperature and impetus at 0.2 g/cm^3 density of loading computed with the BLAKE thermochemical code.[3]

III. RESULTS AND DISCUSSION

The initial step in this assessment of the potential usefulness of 20mm M61 gun as a tool to assess plating efficiency is to determine how much M2 or M9 propellant can be loaded in place of the standard ball powder without exceeding the peak chamber pressure of the M55A2 round. Once this charge weight is known, empirical formulas are available to estimate the wear.[4,5] Wear will also be estimated from peak bore surface temperatures.

Table 3 summarizes the data gathered during the charge assessment. Velocities, V_1 and V_2, are the velocities midpoint between screens 1 and 2 and 2 and 3, respectively, while V_o is the muzzle velocity.

Figure 1 plots peak pressure vs charge mass for the three propellants evaluated along with the standard M55A2 TP-T round. Data for the M2 and M9 propellants are linearly extrapolated to 39.6g to estimate peak pressure with this charge mass. Figure 1 shows only the coarse grade M9 remains below the M55A2 round's maximum pressure with the same propellant mass. Figure 1 also shows an additional four grams could be used without exceeding the standard peak pressure. Whether an additional four grams could be loaded and fired safely was not determined.

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[3] *E. Freedman, "BLAKE, A Ballistic Thermodynamic Code Based on TIGER," Proceedings of the International Symposium on Gun Propellants," Picatinny Arsenal, October 1973.*

[4] *J.M. Frankle and L.R. Kruse, "A Method for Estimating the Service Life of a Gun or Howitzer," BRL Report No. 1852, June 1967.* (AD #A021389)

[5] *C.S. Smith and J.S. O'Brasky, "A Procedure for Gun Barrel Erosion Life Estimation," Proceedings of the Tri-Service Symposium on Gun Tube Wear and Erosion, March 1977.*

TABLE 1. PHYSICAL PROPERTIES OF PROPELLANTS TESTED IN 20mm BARREL

Propellant	No. Perforations	Lot No.	web, mm (in)	surface area/mass m^2/kg (in^2/lbm)
M9 "fine"	seven	PE-480-14	0.61 (0.0241)	1.35 (949)
M9 "coarse"	seven	PE-480-12	0.83 (0.0326)	1.02 (716)
M2	single	HPC 34386-45	0.37 (0.0145)	4.50 (3162)
WC870	ball	-	0.76 (0.03)	4.91 (3450)

TABLE 2. PROPELLANT COMPOSITIONS AND THERMOCHEMICAL PROPERTIES

Ingredient	Percent by Weight M2	M9	WC870
Nitrocellulose (13.15% nitration)	-	-	81.1
Nitrocellulose (13.25% nitration)	75.12	57.55	-
Nitroglycerine	18.92	39.86	10.0
Dibutylphthalate	-	-	5.2
Ethylcentralite	0.58	0.75	-
Barium Nitrate	1.36	-	-
Potassium Nitrate	0.73	1.49	0.6
Diphenylamine	-	-	0.9
Tin Dioxide	-	-	0.8
Carbon	0.3	-	0.4
Residual Solvents	2.3	0.35	1.0
Flame Temperature, K	3,375	3,844	2,800
Impetus, J/g	1,097	1,170	977

TABLE 3. MUZZLE VELOCITY AND PEAK CHAMBER PRESSURE FOR M2 AND M9 PROPELLANTS

Round	Propellant	Charge Mass, g (gr)	V_1, m/s	V_2, m/s	V_0, m/s	Pressure, MPa
1	WC 870*	39.6 (611)	1,027.8	1,025.0	1,030.5	427
2	WC 870*	39.6 (611)	1,034.8	1,033.9	1.035.7	**
3	WC 870*	39.6 (611)	1,046.4	1,044.0	1,047.6	**
4	WC 870*	39.6 (611)	1,029.6	1,025.0	1,034.2	427
5	M2	13.0 (200)	677.6	676.4	678.8	221
6	M2	19.4 (300)	863.8	860.8	866.9	483
7	M2	19.4 (300)	872.3	871.4	873.3	**
8	M2	25.9 (400)	1,009.2	1,004.6	1,013.5	758
9	M9 "coarse"	22.7 (350)	777.2	776.3	778.2	207
10	M9 "coarse"	31.1 (480)	949.5	944.9	954.0	296
11	M9 "fine"	25.9 (400)	948.8	947.3	950.4	317
12	M9 "fine"	32.4 (500)	1,100.3	1,094.4	1,104.3	476

* *M55A2TP-T projectile*

** *Not taken*

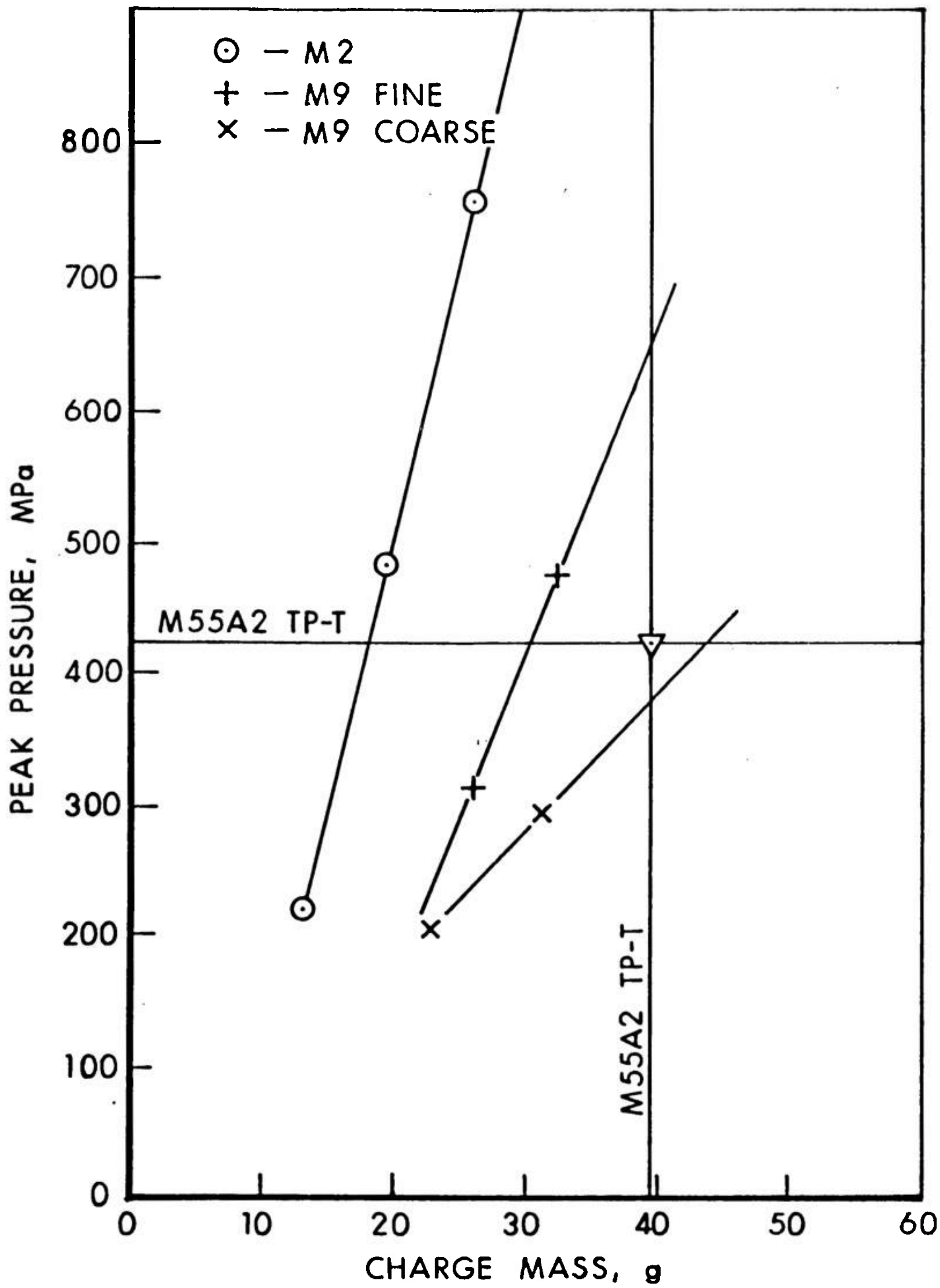

Figure 1. Peak pressure vs charge mass for M2 and M9 propellant

Figure 2 illustrates a similar comparison for muzzle velocity for the three propellants tested along with the value for the M55A2TP-T reference round. An extra 100 m/s could be achieved with the coarse-grade M9 propellant using the standard charge mass. Additional 200 m/s could be achieved at the maximum peak pressure presuming the extra four grams of propellant could be loaded.

One estimate of wear with M9 propellant was made with the Frankle-Kruse formula.[4] Their method was based on work in the UK during World War II in which an empirical formula was devised to compute the maximum bore temperature rise at the origin of rifling from basic interior ballistic parameters as shown below:

$$\theta = \frac{T_0 - 300}{1.7 + 0.38\sqrt{d}\left(\frac{d^2}{c}\right)^{0.86}} \tag{1}$$

where θ = maximum temperature rise at origin of rifling, K,
d = bore diameter, in.,
T_0 = adiabatic flame temperature, K, and
c = charge mass, lb.

The UK workers found the best correlation between gun wear, w, and maximum temperature rise was

$$\ell n\left(\frac{w}{\sqrt{d}}\right) \sim \theta, \ \theta > 600K \quad . \tag{2}$$

Frankle and Kruse applied equation (2) with a least-squares fit to the US Army guns and howitzers listed in Table 4 and found the following equation for diametrical wear/round:

$$\frac{w}{\sqrt{d}} = 1.68 \times 10^{-5}\, e^{0.00785\theta} \quad . \tag{3}$$

Figure 3 illustrates the wear estimated with equation (3) for M9 propellant in a 20mm gun. Figure 3 shows that 39.6g of M9 propellant will wear 5 μ/shot. By comparing this with the wear in Table 4, one sees the M9 loaded 20mm gun will have wear comparable to artillery guns, but well below tank guns.

A further effort to estimate how the wear in the 20mm barrel with M9 compares with wear in Army guns was made by measuring peak bore surface temperatures. Calspan Corporation has demonstrated that peak bore surface temperatures can be computed reliably from measurements of the

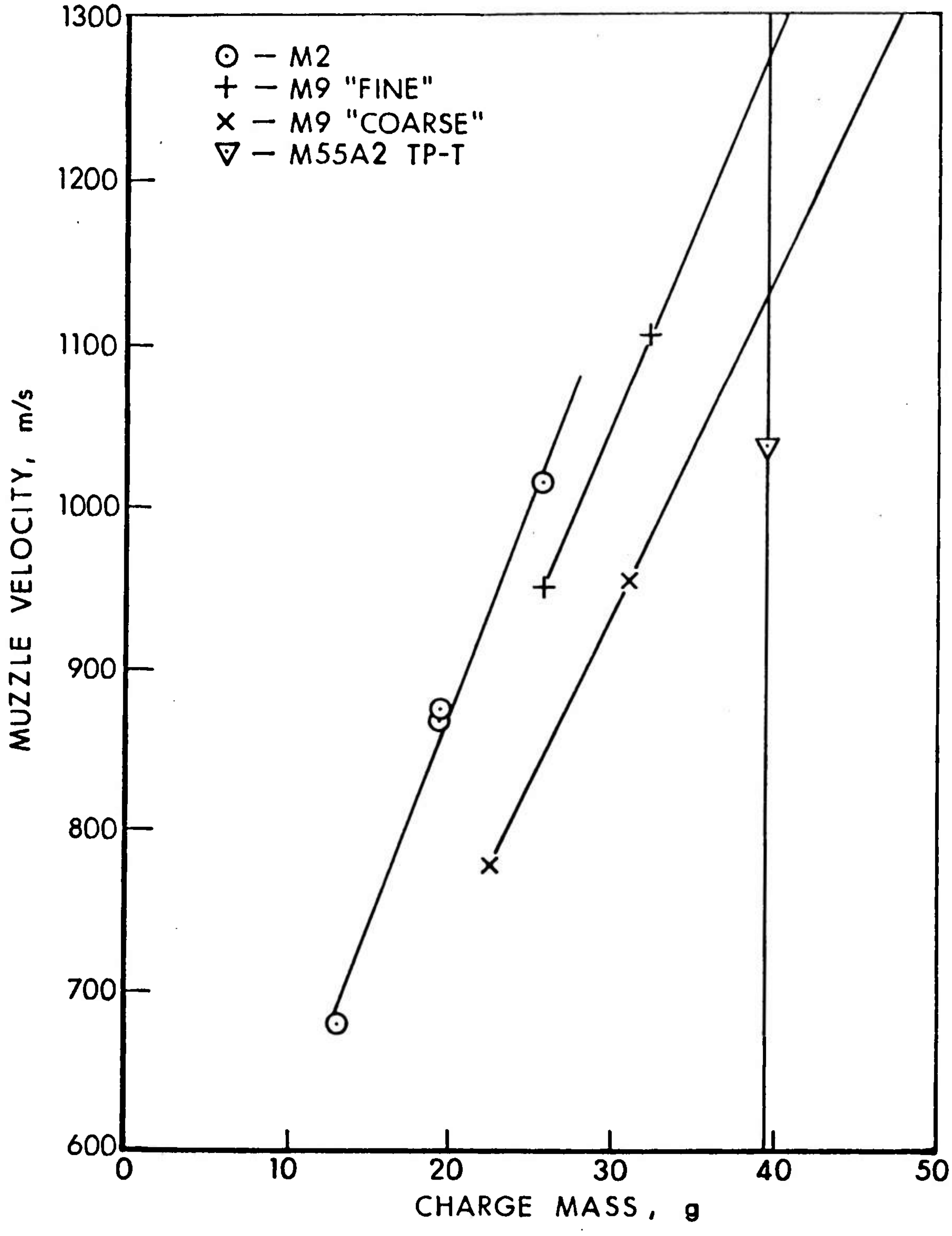

Figure 2. Muzzle velocity vs charge mass for M2 and M9 propellant

TABLE 4. WEAR, SERVICE LIFE, AND INTERIOR BALLISTIC DATA FOR US ARMY GUNS AND HOWITZERS*

Gun or Howitzer	Wt. of Propellant Charge, kg	Type of Propellant	Adiabatic Flame Temp. of Propellant, K	Wear Per Round, μ	Service Life, Rounds
37mm Gun, M1A2	0.128	M2	3372	0.9	2000
37mm Gun, M3	.250	M5	3294	2.6	700
37mm Gun, M4	.070	M2	3373	0.6	3000
75mm Gun, M3	.902	M6	2583	0.1	4700
75mm Gun, M35	1.535	M6	2583	1.1	1300
76mm Gun, M1	1.734	M6	2583	0.8	3000
76mm Gun, M48	2.421	M17	2974	7.3	350
90mm Gun, M1	3.309	M6	2583	1.4	3800
90mm Gun, M3	3.688	M6	2583	1.9	2000
90mm Gun, M41	4.014	M17	2974	7.1	700
105mm How, M2A1	1.283	M1	2433	0.09	20,000
105mm How, M68	5.483	M30	3040	19	100
120mm Gun, M1	10.603	M6	2583	12	500
120mm Gun, M58	13.350	M17	2974	25	250
155mm How, M1A1	5.982	M1	2433	0.2	15,000
155mm Gun, M2	13.999	M6	2583	4.0	700
175mm Gun, M113	25.202	M6	2583	13	400
8 in How, M2	12.723	M1	2433	0.6	6000
8 in Gun, M1	14.851	M6	2583	13	700
240mm How, M1	36.174	M6	2583	2.5	2000

Table I in reference 4 converted to metric units.

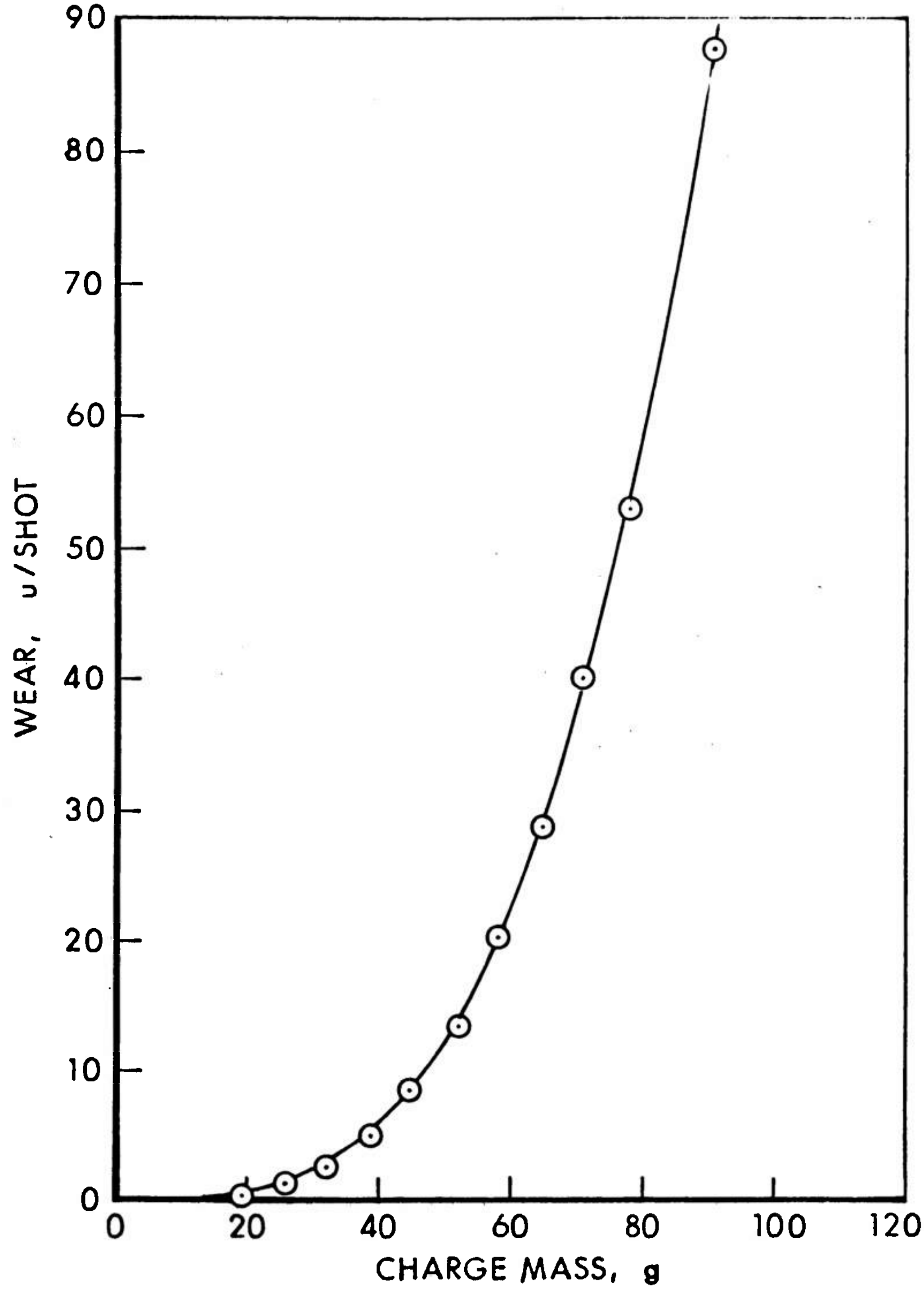

Figure 3. Estimated wear vs charge mass for M9 propellant in 20mm gun

total heat input.[6] In earlier experiments, Calspan Corp. investigators measured heat input and computed bore surface temperatures in an M185 cannon firing various 155 mm propelling charges.[7] Comparing measured peak surface temperatures for the 20mm barrel with those computed by Calspan is another way to estimate the potential of the 20mm barrel to mimic wear in large-caliber guns.

Table 5 lists the peak bore surface temperatures computed from measured heat inputs. The wear/round is available from Proving Ground tests[8] with the exception of the XM208 charge without liner.

TABLE 5. WEAR AND PEAK BORE TEMPERATURE RISES FOR 155mm CHARGES

Charge Type	Peak Bore Temp. Rise, K	Wear, μ/round
M4A2	756	0.01
M119	917	0.9
XM1203E2	961	1.4
XM119E4	969	1.1
XM201E2	1,056	2.6
XM119	1,067	2.8
XM208 (no liner)	1.261	*

Not available.

[6] *F.A. Vassallo and W.R. Brown, "Shock Tube Gun Melting Erosion Study," BRL Contract Report No. CR-00406, August 1979.* (AD #A076219)

[7] *F.A. Vassallo, "An Evaluation of Heat Transfer and Erosion in the 155 mm M185 Cannon," Calspan Technical Report No. VL-5337-D-1, July 1976.*

[8] *J.R. Ward and T.L. Brosseau, "Effects of Wear-Reducing Additives on Heat Transfer into the M185 Cannon," BRL Memorandum Report No.* 2730, *February 1977.* (AD #A037374)

The Appendix illustrates recorded bore surface temperature and chamber pressure vs time for two standard rounds (61 and 64) and one round with 31.1 g of M9 propellant (round 65). Peak bore temperature increases were 761K and 782K for the two standard rounds while the M9 propellant produced a 963K temperature rise. If one uses Table 5 as a correlation between wear and peak surface temperature, one concludes the standard round should produce wear comparable to the M4A2 charge. Niiler and Birkmire[9] measured single-shot wear of 0.02 μ/round for the M55A2 projectile which lends some credence to use of Table 5 to estimate wear from peak surface temperatures. Using Table 5 and the 963K temperature rise for M9 propellant, one predicts the M9 propellant will produce wear comparable to the XM203E2 charge. Thus, the wear-peak surface temperature correlation also suggests M9 propellant in the 20mm barrel mimics wear of current howitzers.

A final point to consider is what needs to be done to get 25 μ/shot in the 20mm barrel. Figure 3 illustrates wear vs charge mass for M9 propellant which suggests the charge mass must be 60-70g to get such wear. This would require a much larger chamber to accomodate the extra propellant. Figure 4 shows what wear might be expected if the charge mass is fixed at 39.6g, but the flame temperature is allowed to increase. Figure 4 was constructed with various values of T_0 in equation (1) with a fixed charge mass and diameter to estimate θ, and use of equation (3) to estimate wear/round. Figure 4 implies flame temperatures in excess of 4,500K would be needed.

IV. CONCLUSIONS

1. M9 propellant can be substituted in the M55A2TP-T round for the standard WC870 ball powder to produce 100 m/s higher velocity without exceeding the peak chamber pressure of the standard M55A2TP-T round.

2. The wear estimated in the 20 mm barrel firing M9 propellant is comparable to that of existing howitzers and tank guns firing rounds with additives.

3. Wear of 25-50 μ/shot is desired in an erosion test device for evaluating future coatings or liners. In the 20mm barrel, this can be done by doubling the charge mass of M9 propellant or by using a propellant with a flame temperature in excess of 4,500K.

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[9] *R. Birkmire and A. Niiler, "Applications of the Radioisotope Wear Measurement Technique," BRL Technical Report 02075, June 1978.* (AD #A058307)

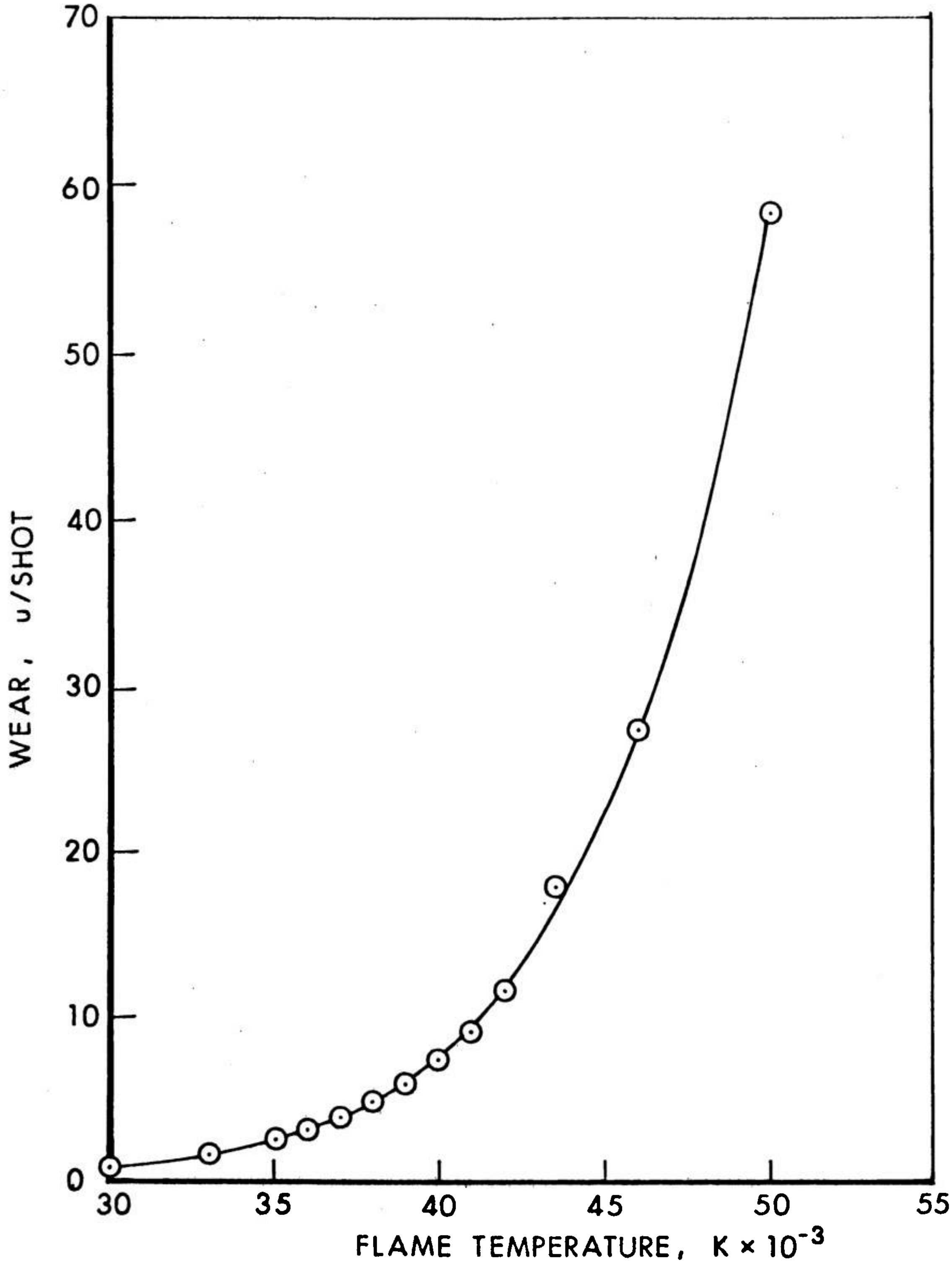

Figure 4. Estimated wear vs flame temperature for 39.6g propellant charge in 20mm gun

APPENDIX

PLOTS OF TEMPERATURE VS TIME AND PRESSURE VS TIME

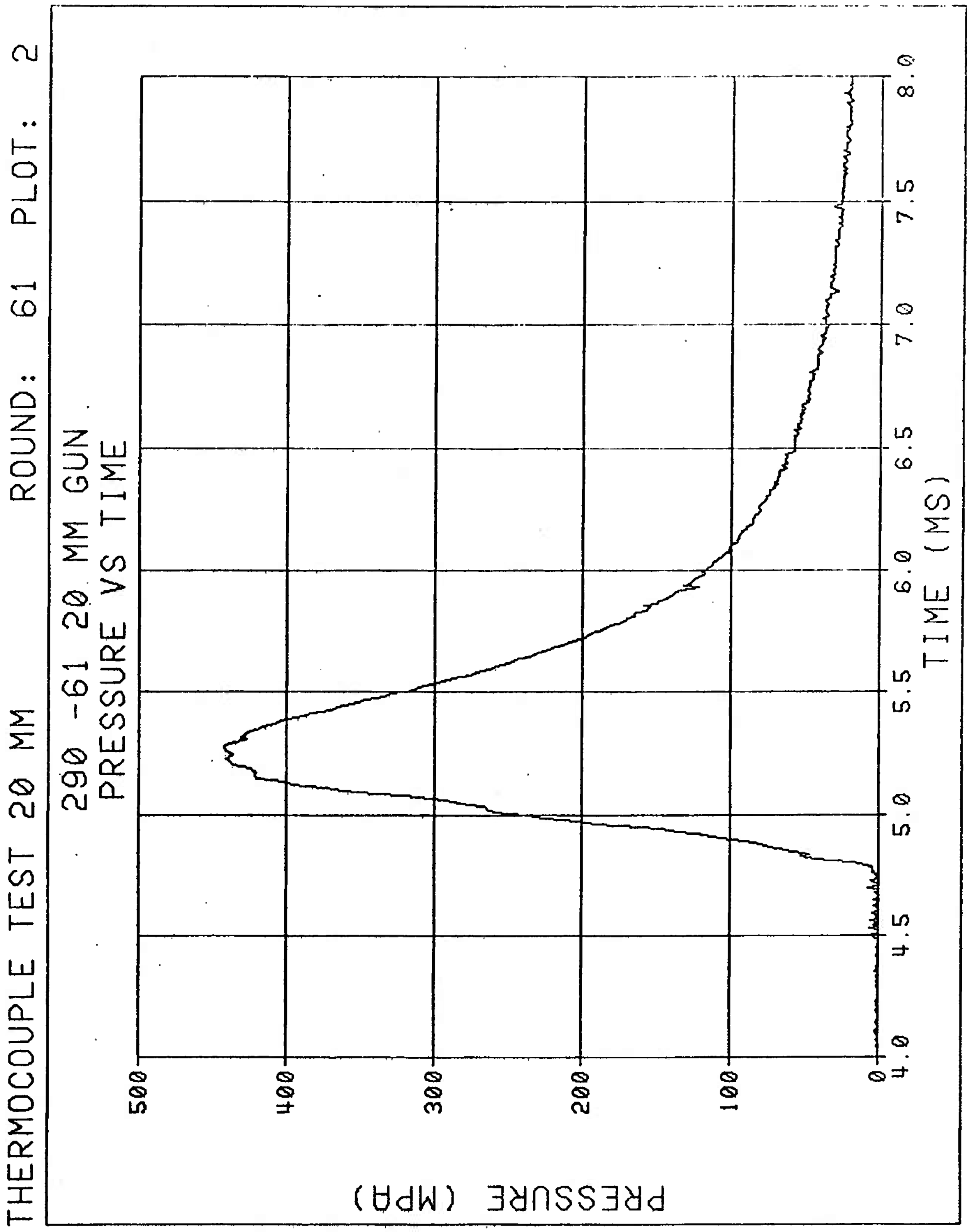

Figure A1. Ident. 290-61 Pressure *vs* Time

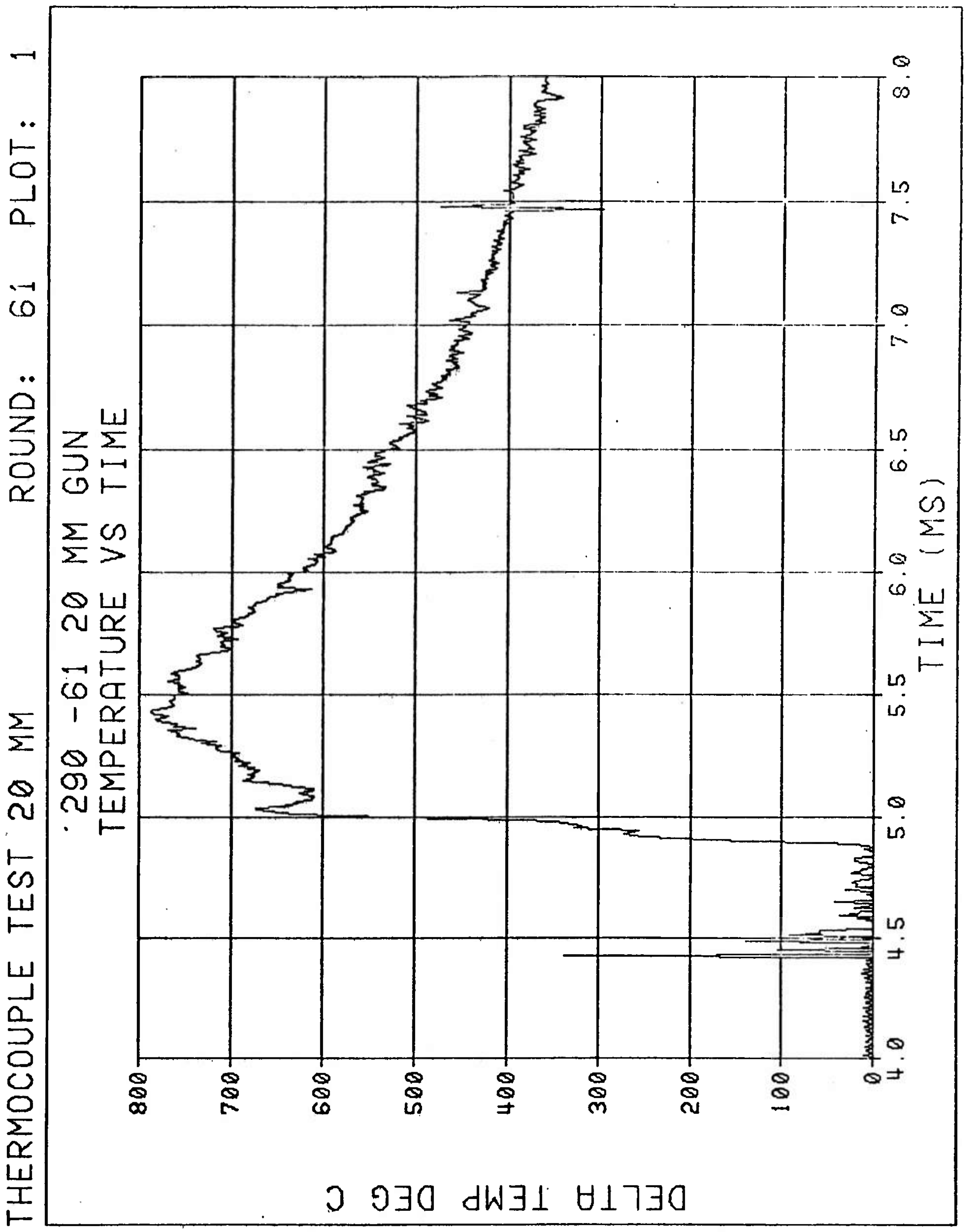

Figure A2. Ident. 290-61 Temperature vs Time

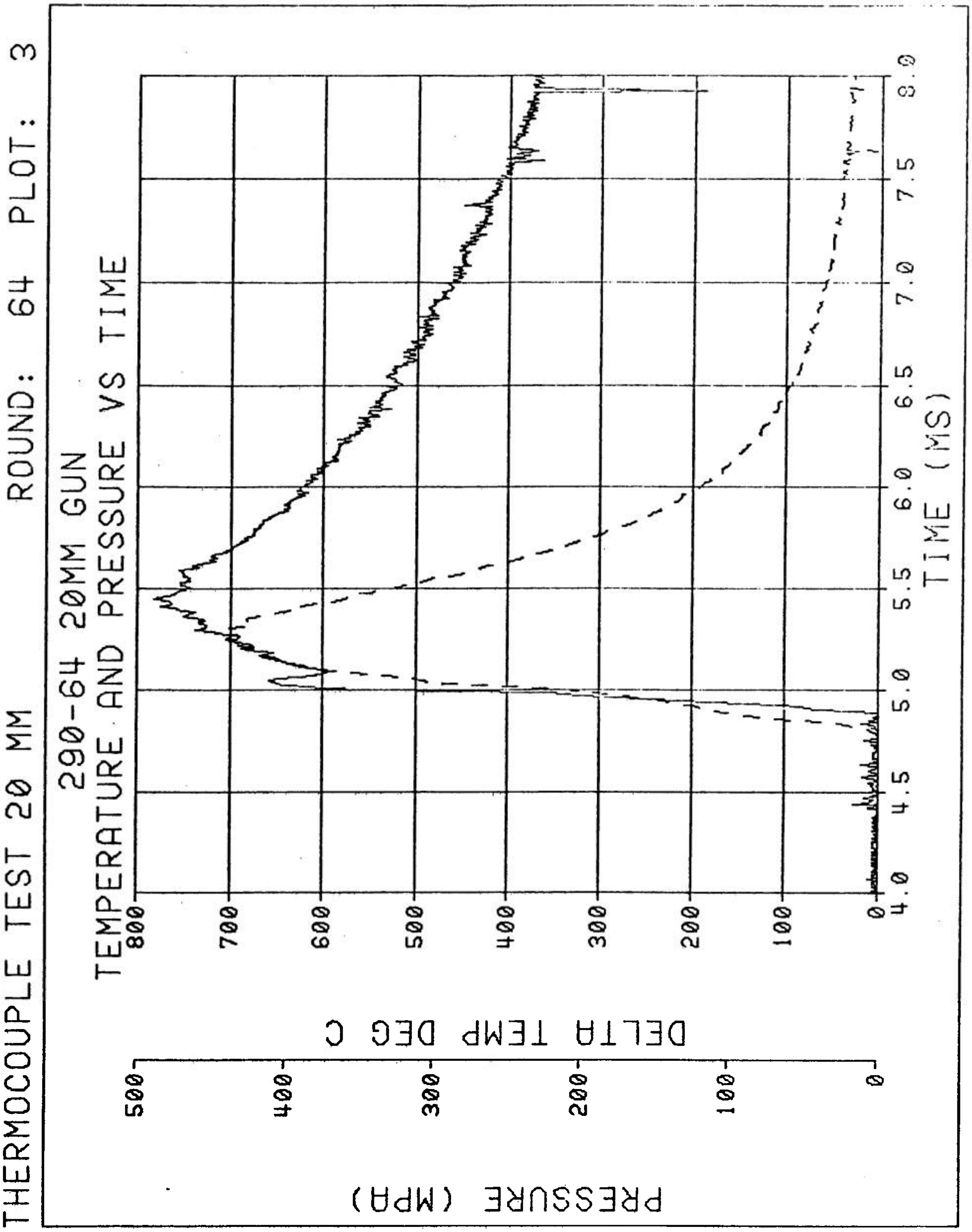

Figure A3. Ident. 290-64 Temperature and Pressure vs Time

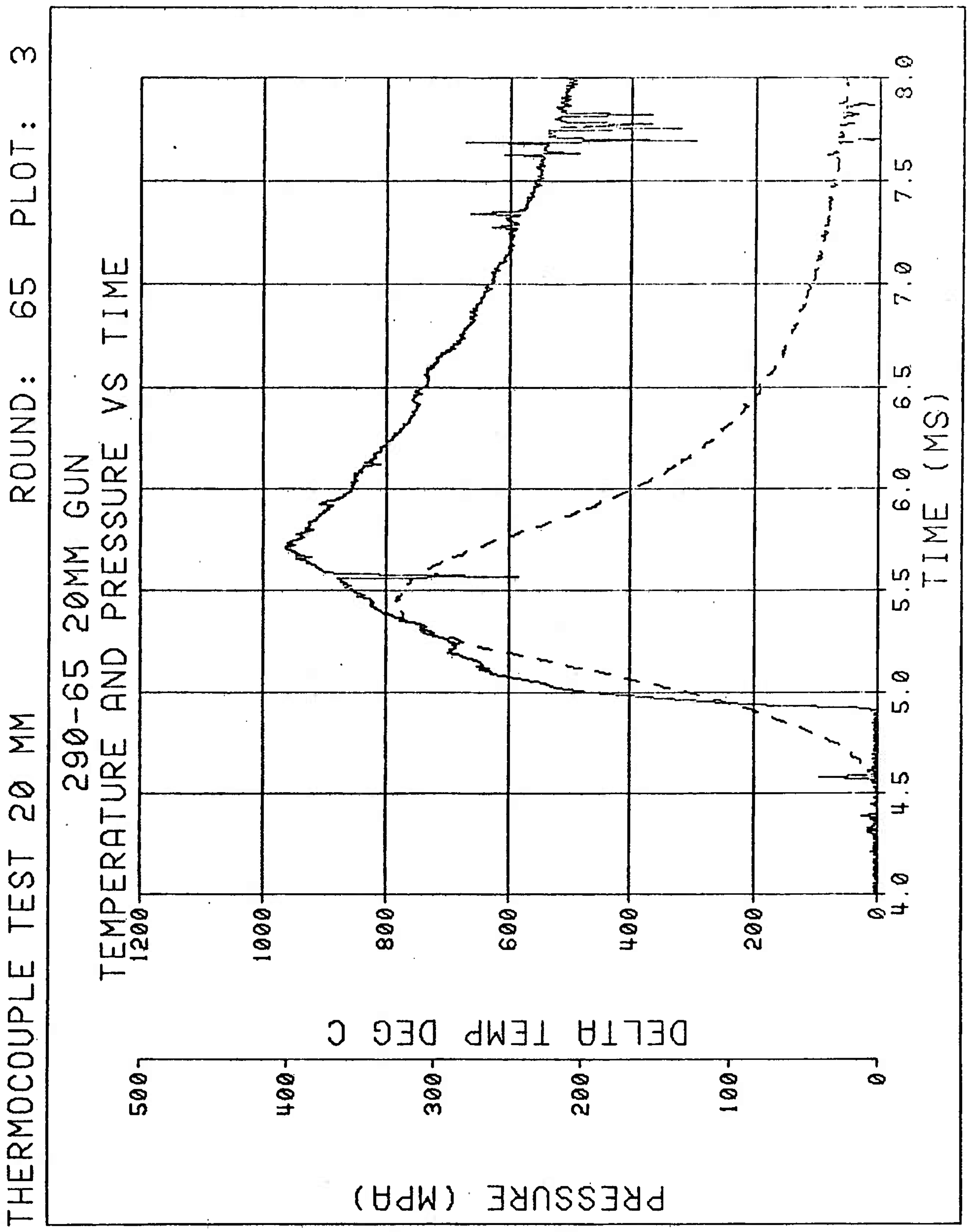

Figure A4. Ident. 290-65 Temperature and Pressure vs Time

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5. C.S. Smith and J.S. O'Brasky, "A Procedure for Gun Barrel Erosion Life Estimation," Proceedings of the Tri-Service Symposium on Gun Tube Wear and Eorsion, March 1977.

6. F.A. Vassallo and W.R. Brown, "Shock Tube Gun Melting Erosion Study," BRL Contract Report No. CR-00406, August 1979. (AD #A076219)

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